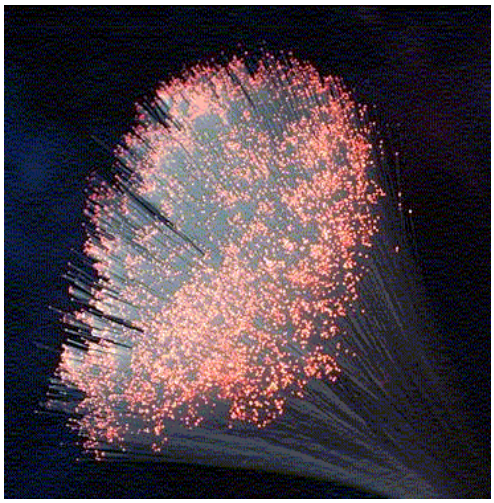
Introduction to Fiber Optic Systems



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Course Overview

- Communications applications
  - High data rate-distance products
  - WDM (wavelength-division multiplexing) technology
  - High data integrity (BERs $<10^{-9}$)
  - Point-to-point links
    - » Long-distance terrestrial telcomm
    - » Underwater-cable telcomm
  - Network applications
    - Local-area computer networks (LANs)
    - Wide-area telecommunications networks (WANs)
- Subjects
  - Fibers
  - Splices, connectors, and couplers
  - Sources
  - Receivers (detector and preamp)
  - System analysis
    - » Link margin
    - » Link data rate
  - Fiber data networks (FDDI and SONET)

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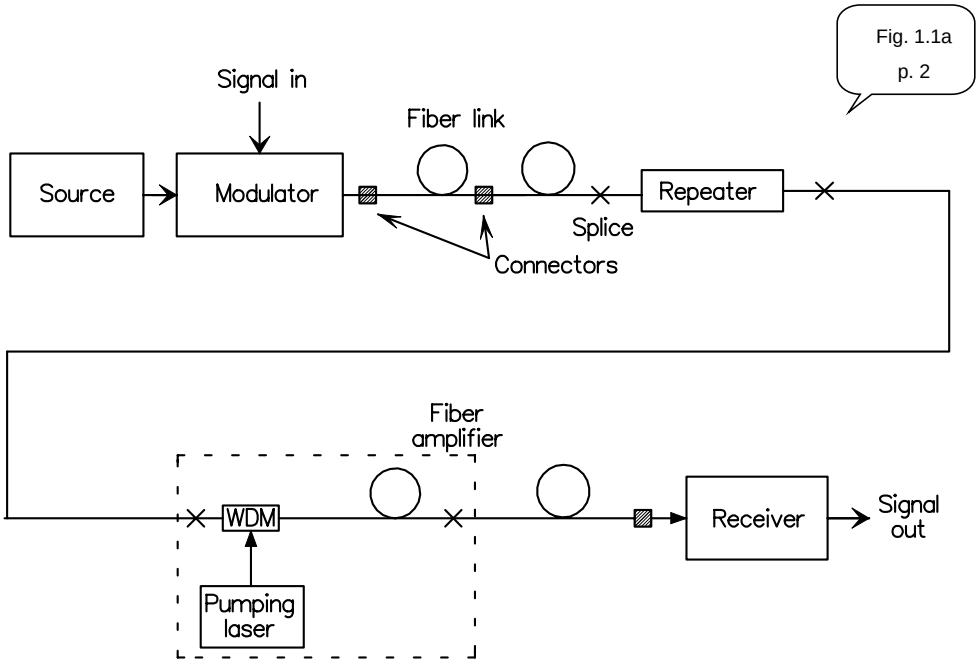
Course Goals

- Fiber vocabulary
- Why fibers?
- Link analysis and design
- Exposure to trade-off issues

Typical Early Fiber Link



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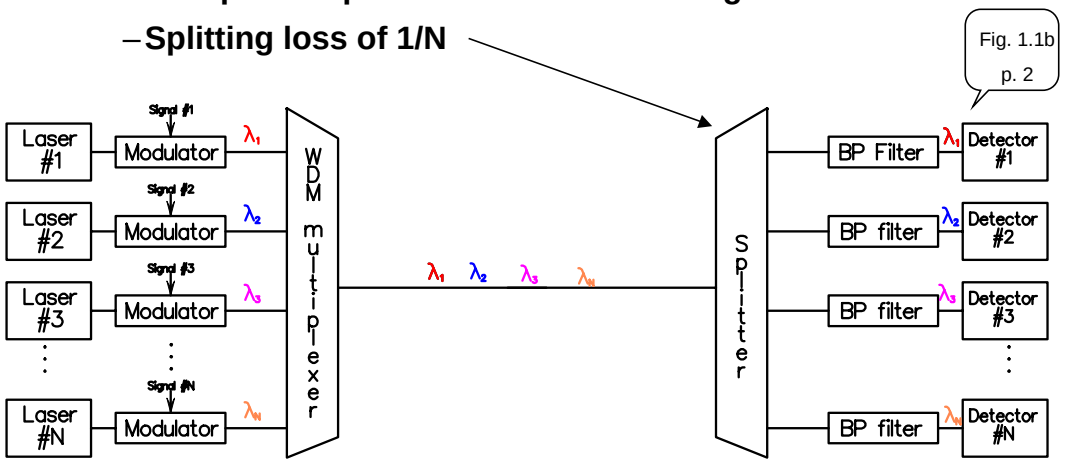
- Optical source
  - ☞ Semiconductor laser or LED
- Modulator
  - ☞ Analog or digital
  - ☞ Direct modulated source or external modulator
- Set of connectors or permanent fiber splice
  - ☞ Join fiber lengths
- Repeater
  - ☞ Electronically detect and regenerate signal
- Optical amplifier
  - ☞ Amplify signal power
- Optical receiver (detector, preamp, logic circuits)
  - ☞ Recover transmitted signal

Typical WDM Fiber Link

- **WDM - "wavelength division multiplexing"**
  - **Multiple independent channels on single fiber**
  - **Splitting loss of 1/N**



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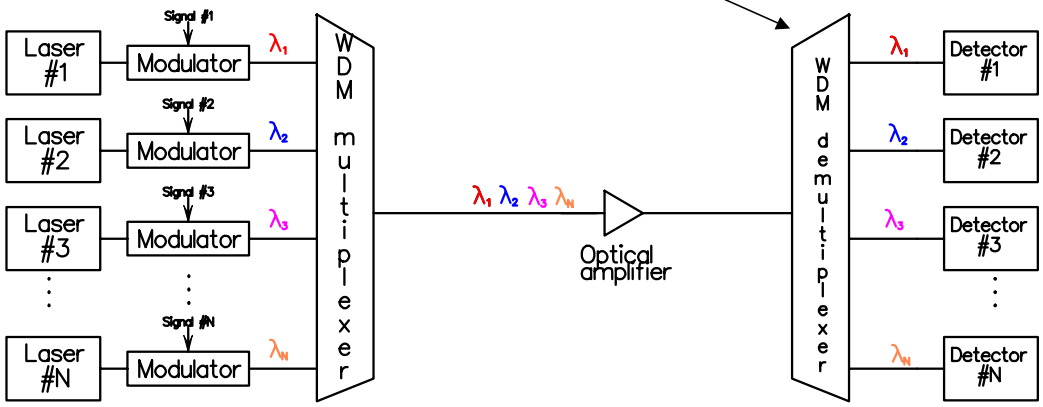
Alternative WDM

- **Wavelength demultiplexer sorts wavelengths**
  - **No splitting loss**



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Decisions, Decisions, Decisions.....

- Signal
  - Analog or digital?
- Source:
  - LED or laser? Wavelength?
  - Modulation format
    - » AM, FM for analog signals
    - » OOK, FSK, PSK for digital waveform
  - Cost, reliability, output power level?
  - Temperature stability?
- Detector:
  - Detector material (wavelength) ?
  - Sensitivity?
  - Cost?
  - Temperature stability?

- Fiber:
  - Attenuation?
  - Bandwidth (single-mode or multimode) ?
  - Distance?
  - Cabling strength members, power conductor, size, weight?
- Connectors and splices:
  - Splices or connectors ?
  - Splice under operating conditions?
  - Keep out water or gases?
- Etc., etc...

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Why Fibers?

- **Wide bandwidth**
  - **Fiber bandwidth & losses independent of diameter**
- **Lower costs than copper**
  - **For high bandwidth signals**
  - **Cost-bandwidth crossover point constantly decreasing**
- **Light weight & low volume**
  - **"50 miles per gallon"**
- **Immunity from electromagnetic interference (EMI)**
  - **No EM pickup**
  - **Elimination of crosstalk**
- **Elimination of sparking**
- **Compatibility with modern solid state devices**

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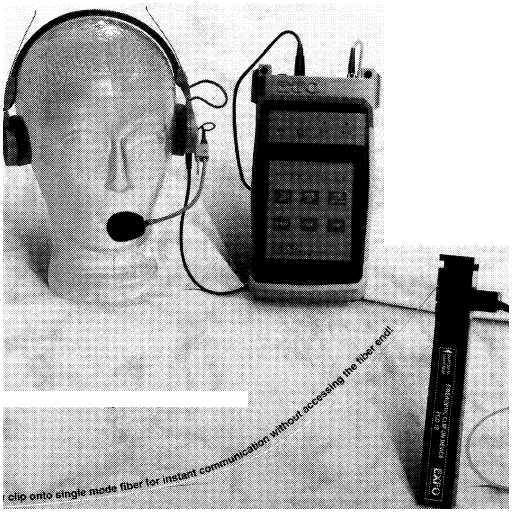
- Bandwidth needs constantly increasing
  - ☞ Solution: increase carrier frequency
    - ✳ HF to VHF to UHF to microwaves to millimeter waves and, finally, light waves
- Coax losses increase linearly with bandwidth
  - ☞ Lower losses by increasing diameter

Example of Fiber Voice Communicator



Data Rate and Bandwidth

- **Signal frequencies: 0 to *BW* Hz**
- **Sampling:**
  - **Nyquist criterion says sample wave at a rate equal to or greater than twice *BW***
    - » ***S x BW***
    - » ***S* ranges from 6 to 10**
- **Digitization: Number of bits per sample *N* depends on accuracy required**
- **Bit rate (b/s):** $B_R = S \times N \times BW$
- **Required link bandwidth *B* (Hz) for bit rate of B_R:**

$$\boxed{B \approx B_R / 2}$$

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- Ex. HDTV
  - ☞ 1000 x 1000 pixels, 12 bits per pixel, 3 colors, 40 frames per sec, uncompressed

$$B_R = (10^3)(10^3)(12)(3)(40) = 14.4 \text{ Gb / s}$$

$$B = B_R / 2 = 7.2 \text{ GHz}$$

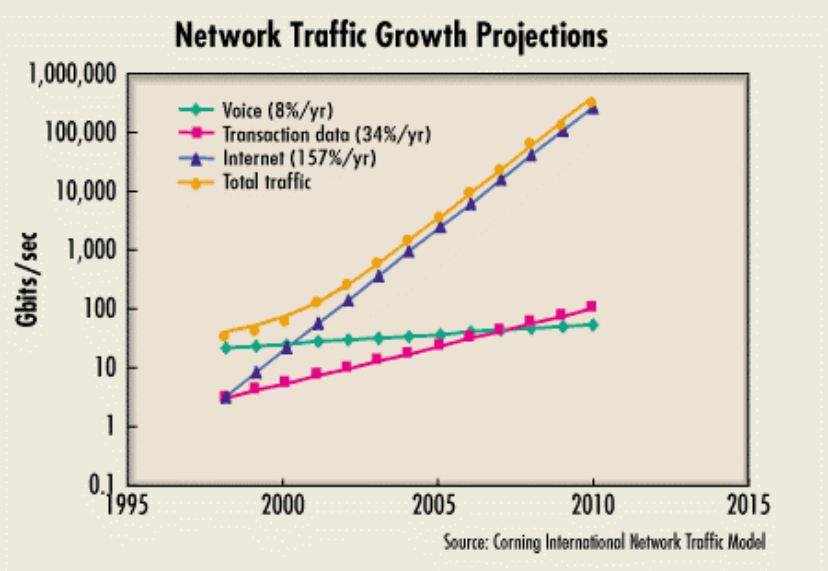
Standard Telcomm Data Rates

Tables 1.1 & 1.2, p. 4

Name	Data rate North America	Number of voice channels
DS-0	64 kb/s	1
DS-1 (T1)	1.544 Mb/s	24
DS-2 (T2)	6.312 Mb/s	96
DS-3 (T3)	44.736 Mb/s	672
DS-4 (T4)	274.176 Mb/s	4,032
(TBD)	1.7 Gb/s	20,000

Japan	Europe
1.544 Mb/s	2.048 Mb/s
6.312 Mb/s	8.448 Mb/s
32.064 Mb/s	34.364 Mb/s
97.728 Mb/s	139.264 Mb/s
396.20 Mb/s	565.148 Mb/s

Bandwidth demand



Projections for network traffic growth show huge increases in bandwidth demand.

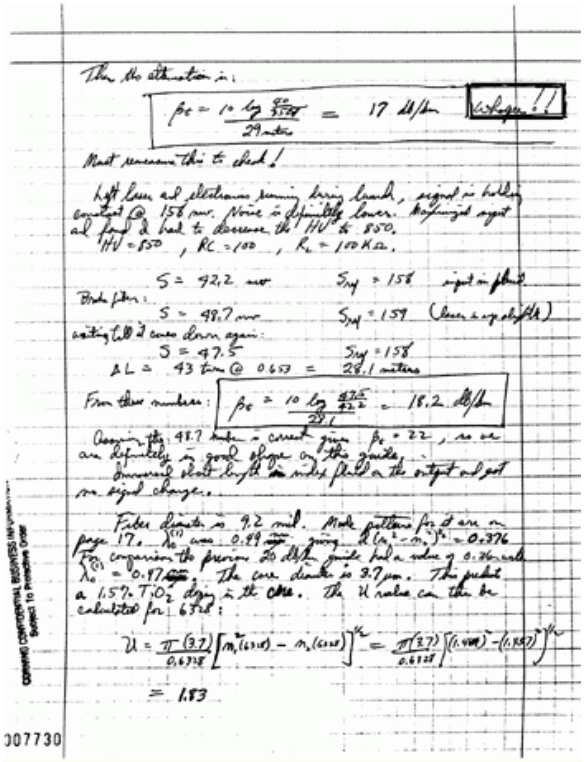
Why Not Fibers?

- Lack of bandwidth demand
  - HDTV requires high bandwidth
- Lack of standards
  - Standards being set by
    - DoD
    - Telecomm industry
    - Computer industry
- Radiation darkening
  - Depends on dose, exposure, glass materials, impurity types and levels
  - Clears with time

History

- 1850s:
  - Principle of total internal reflection: Tyndall
- 1950s:
  - Development imaging optical fibers for medical and NDT applications (short distance)
- Late 1960s:
  - Kao and Werts independently propose communications applications
    - » 20 dB/km losses to be competitive with RF repeaters
- Early 1970s:
  - Glass purification techniques reduce losses to few tenths of dB/km (see notes)
  - *First-generation* technology
    - » Sources/receivers: visible and near-IR (from 600 to 920 nm)
    - » Fibers: multimode fiber bundles
- Late 1970s, early 1980s:
  - *Second-generation* technology
    - » Sources/receivers: visible and near-IR (600 to 920 nm)
    - » Fibers: individual multi-mode fiber
- Mid -1980s to present::
  - *Third generation* technology
    - » Sources/receivers: near-IR (1300, 1550 nm)
    - » Fibers: individual single-mode fibers
- Present:
  - *Fourth generation* technology
    - » 1550 nm operation to use fiber amplifiers
    - » Several wavelengths per fiber (WDM)
  - Wavelength addressable net-works

The three Corning scientists credited with the invention of low-loss optical fiber in 1970: Dr. Donald Keck, Dr. Bob Maurer, and Dr. Peter Schultz.



The page from Dr. Donald Keck's lab notebook recording the breakthrough loss measurement of 17 dB/km in August 1970.

Alternate Texts

- G.P. Agrawal, *Fiber-Optic Communication Systems, 2nd Ed.,* Wiley-Interscience, 1997
- **J. Hecht, *Understanding Fiber Optics, 3rd Ed.,* Prentice Hall, 1999.**
- **P.E. Green, Jr., *Fiber Optic Networks,* Prentice Hall, 1993.**
- G. Keiser, *Optical Fiber Communications*, 3rd Edition. McGraw-Hill, 2000.
- **J.C. Palais, *Fiber Optic Communications*, *5th Edition*. Prentice Hall, 1997.**
- **J.P. Powers, *Introduction to Fiber Optic Systems*, Richard D. Irwin, Inc., 1993.**
- **J.P. Powers, *Introduction to Fiber Optic Systems, 2nd Edition*, WBC McGraw-Hill (formerly Richard D. Irwin, Inc.), 1997.**
- **J. Senior, *Optical Fiber Communications: Principles and Practice*. Prentice-Hall, 1998.**
- **A. Yariv, *Optical Electronics in Modern Communications, 5th Ed.,* Oxford University Press, 1997.**

Intro-15

- US research journals
  - Through 1983:
    - IEEE Journal on Quantum Electronics
    - Applied Optics
    - Bell System Technical Journal
    - Other journals
  - After 1983:
    - Journal of Lightwave Technology
  - After 1990:
    - IEEE Lightwave Communications Systems Magazine} (changed to IEEE Lightwave Telecommunications Systems Magazine; ceased publication November 1992)
  - Device and technique research results:
    - IEEE Photonics Technology Letters
    - Electronic Letters